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Numerical and Experimental Analysis of a Spiral Horizontal Axis Wind Turbine

[1]Muhammad Abid, [1]Khasan S. Karimov and [2]Hafiz A. Wajid

[1]Faculty of Mechanical Engineering,
GIK Institute of Engineering Sciences and Technology, Topi, KPK, Pakistan
[2]Department of Mathematics,
COMSATS Institute of Information Technology, Lahore, Pakistan

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Abstract: This paper presents results of design, analysis, manufacturing and testing of a spiral horizontal axis wind turbine. In first step, modeling and computational fluid dynamic (CFD) analysis was performed. Helix blades angle for spiral rotors of outer and inner diameter of 0.85 and 0.45m, respectively was optimized. In the second step, as per optimized spiral rotor dimensions, a prototype was manufactured. Experiments were carried out for torque and power calculations; obtained results are discussed.

Key words: Wind turbine · Numerical and experimental analysis · Spiral horizontal axis · Torque and power calculations

INTRODUCTION

Power generation by suitable biodiesel for the gas turbine is considered as green energy [1]. It has been reported that even ocean wave energy assisted by wind power produced significant power by point absorber wave energy convertors [2]. In fact power generated by wind turbines is an environmental friendly method of producing electrical energy. The rotors are designed using aerodynamic principles with the purpose of extracting some of the kinetic energy from the wind by developing rotational forces on the rotor, when placed in sufficiently strong wind. There is significant potential for power generation from wind in Pakistan. The coastal regions of Sindh and Baluchistan offer ideal locations for wind farms. There is also impressive potential across the northern border of the provinces of Punjab and Khyber Pukhtoonkhwa. Generation of electricity through wind is not something new. India, the fifth in line of countries in the world for the generation of electricity, is producing more than 13,000 MW of electricity by utilizing wind turbines. It is not only manufacturing these turbines but exporting them toother countries. Once a wind turbine is installed, it would produce energy for 25-30 years free of cost as no other fuel is used except wind through this mode of production. Due to increase in population and technological trends, there is a growing need for energy. At present, Pakistan alone there is an estimated power shortage of approximately 4000 MW (18%) [3]. Energy shortage is a real crisis in the developing world; such deficiency is increasing as the price fuel increasing. Therefore, more funds are invested in research on renewable energy and it is rapidly becoming one of the important research areas of today.

This paper provides analysis and development of a working spiral airfoil wind turbine (SWT) to produce electricity. It is drag type device which takes advantage of the air flow produced around smooth spiral shaped blades. Preliminary analysis and testing has revealed that this device starts up at a very low speed when compared to other horizontal axis wind turbines (HAWT). It also offers better performance at low wind speeds when compared to other turbines of comparable dimensions. In SWT air is directed parallel to the horizontal axis of the turbine. When flowing air comes in contact with the rotors, it imparts a force and hence a moment which produces rotational motion about the turbine axis. The surface of the rotors is kept smooth to minimize the

Corresponding Author: Muhammad Abid, Faculty of Mechanical Engineering, GIK Institute of Engineering Sciences & Technology, Topi, KPK, Pakistan. E-mail: abid@giki.edu.pk.

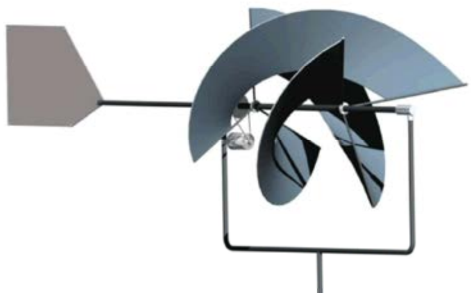

Fig. 1: The 3D Spiral Wind Turbine Model

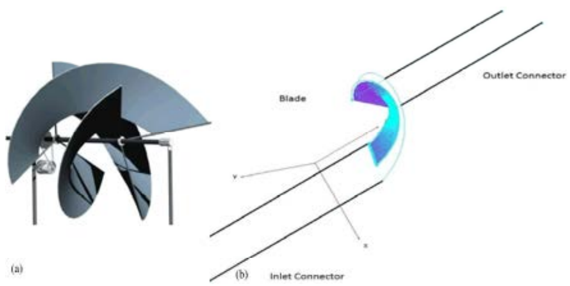

Fig. 2: (a) Model of spiral blade, (b) Extension of Inlet and Outlet Domains

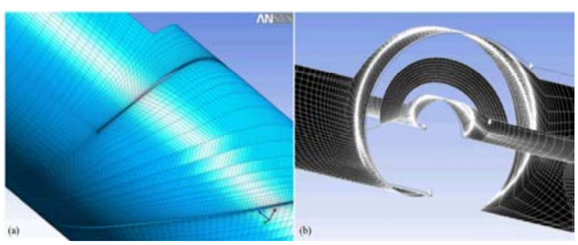

Fig. 3: (a) Meshing at 50% blade span wise location, (b) Meshing of the inlet and outlet domains

effects of turbulence. Fig. 1 shows design of a SWT which is an emerging concept with a higher efficiency as compared to a conventional three bladed propeller type wind turbine, low start-up speed, low cost of manufacturing and easy to assemble [4].

Modelling and Meshing of the Blades: The dimensions of the SWT were selected based on the availability of testing in the wind tunnel lab; i.e. blade outer radius = 0.85m, blade inner radius= 0.45m,length of the blade collar = 0.8m and helix Angle (between leading and trailing edge of blade) = 200 degree.The blades are modeled using Pro-Engineer software [5] as shown in Fig. 2a.

Turbo-Grid [6], a module of ANSYS CFX [7] required hub and shroud clearance of SWT. Therefore, a domain of influence around the blades of SWTis defined in terms of extrapolated dimensionsfor the inner diameter (0.3m), outer diameter(1.5m) and a span wise blade length (0.2m).After converting the geometric model to a combination of grid points, the inlet and outlet domains are specified in Gridgen[8]. Two "2 point connectors" are made starting from the vertex of the inlet blade side to specified points along the axis of rotation and the same procedure is carried out for the outlet side as shown in Fig. 2b.

Table 1: Mesh Sensitivity Analysis

	Baseline	Coarse	Fine
Nodes	458419	269739	636961
Elements	428124	248040	600928
Max. Face Angle	162.56	157.29	158.80
Min. Face Angle	12.44	12.57	13.62
Percent Error	0	1.62	1.09

ANSYS TURBOGRID Ver.12.1 was used to generate a structured mesh for the entire flow domain with 428124 quadrilateral mesh elements. In order to capture the flow separation effects in a suitable manor,H/J/C/L Grid method was used which also included an O-Grid around the blade, resulting in increased mesh sensitivity around the blade. Fig. 3a shows mesh elements at 50% span wise location of the blade with concentrated mesh near the blade. Fig. 3b depicts the meshing of the inlet and outlet domains. A mesh sensitivity analysis was also carried out in order to assess the validity of the numerical simulation, using three different mesh configurations which are summarized in Table 1.

Boundary Conditions: For CFD Analysis, a single blade was modeled and periodic boundary condition was applied to the model along withentire rotor. The rotor was placed in a rotating fluid domain with stationary inlet and outlet. Air at 25ºC was the fluid. The morphology of the domain was set as continuous. A reference pressure of 1atm was specified for the entire domain. Heat transfer effects were neglected by specifying the entire domain as an isothermal zone. The inlet boundary condition for the mass and momentum equations was specified as normal speed. A constant static pressure boundary condition was applied at the outlet and blade which was set as a no slip wall. Based on the limitations of the K-å turbulence model for not accurately predicting the flow separation effects at wall faces, shear stress transport (SST) Turbulence model was used to capture desired manor the flow separation effects on the face of the blades [7].

RESULTS AND DISCUSSION

Performance coefficient defines the performance of a wind turbine and is expressed with the variation in tip speed ratio (TSR). The TSR is defined as a ratio of the velocity of wind blowing from the rotor blade against the wind velocity at the tip of the blade and is a non-dimensional figure and can be derived as per equation 1.

$$\text{TSR} (\lambda) = R\Omega/v \quad (1)$$

In reality, the rotational speed of the rotor blade changes according to the speed of wind blowing into the system.But, if this fact is taken into account in the numerical analysis, the actual wind velocity change in blade rotation speed, which differs depending on the wind velocity, must be obtained through an experiment. This can be quite inconvenient. Therefore, this study fixes the wind velocity by using the non-dimensional number of TSR and changes only the blade rotation speed. This approach resembles Reynolds similarity principle. Even if the wind velocity is fixed, as long as only one variable among the other variables such as the blade's radius (R) and rotational speed (Ω) is adjusted and all other conditions are identical; there is no problem in the numerical analysis [9]. The calculation conditions were set as follows: the velocity of air coming normal to the inlet was set at 5 m/s. The rotational speed of the blade was varied from 30 rpm to 140 rpm and TSR was observed in the range of 0.18 to 0.87. The torque on each blade was calculated using the torque function available in ANSYS-CFX 12.1. Power is obtained by the product of the total torque acting on all the blades with the rotational speed. Performance coefficient for a wind turbine is defined as the ratio of the extracted power from the wind to the total power available in the airstream at a fixed wind speed. Ten case studies were performed and the results are summarized in Table 2. The maximum Performance Coefficient (C_p) of 0.488 is obtained as per equation 2 at a wind speed of 5 m/s and a rotational speed of 100rpm. As the Betz limit places a limit on the maximum performance coefficient for a wind turbine to be 0.593 [10]. Hence, these results indicate a high efficiency in comparison with other wind turbine designs.

$$C_p = \frac{Power\ Extracted\ from\ wind}{\frac{1}{2}\rho A V^3} \quad (2)$$

Table 2: Effect of varying rotational speed on TSR and performance coefficient

	Inlet Velocity (m/s)	RPM	TSR	C_p
Case 1	5	30	0.1885	0.2577
Case 2	5	40	0.2513	0.3195
Case 3	5	50	0.3141	0.3729
Case 4	5	60	0.3770	0.4152
Case 5	5	70	0.4398	0.4503
Case 6	5	80	0.5026	0.469
Case 7	5	90	0.5655	0.4824
Case 8	5	100	0.6283	0.4877
Case 9	5	120	0.7540	0.4806
Case 10	5	140	0.8796	0.4588

Where, ρ = Density of air, A = Cross Section Area, V = Wind speed

Pressure difference between the front and back sides of the blade ranging from -75 to 85 Pa at the fixed wind speed (5 m/s) produced resultant force on the blades which is resulting in the rotational motion of the shaft [Fig. 4a] [11]. Fig. 4 billustrates swirling airflow on the downstream of the rotor.

Fabrication and Assembly of Blades for Testing: Based on Pugh and Weighted index method, fiber glass material was selected. Based on the CFD analysis and optimized helix angles and size of the SWT blades; spray lay-up an open-molding composites fabrication process where resin and fiber layers (reinforcements) are sprayed onto a reusable mold was used.A triangular-shaped structure was designed to hold the axial loads and the weight of the turbine itself with shaft held together by bearings at each end. A pulley made of Teflon material was also attached to the shaft for testing purpose. Final assembly and testing arrangement is shown in Fig. 5.

A digital anemometer was used to measure the wind velocity at inlet of wind turbine. Different values of air speed were taken. First reading was taken at the center of wind tunnel and then moving radially outward. Average value was taken as final air speed. The fan speed of the wind tunnel was changed in order to achieve different wind velocities at the exit. First the startup speed of the turbine was calculated, it was that speed at which the turbine starts to rotate (without any load). This was found out to be 0.85 m/s. The shaft torque and power were determined at different inlet air velocities ranging from 1.7 ~ 8.5 m/s and the RPM of shaft was determined at that specific wind speed using a tachometer. Further experiments were performed to measure the torque and shaft power produced at different wind velocities. SWT was placed 4ftaway from the wind tunnel so that air profile

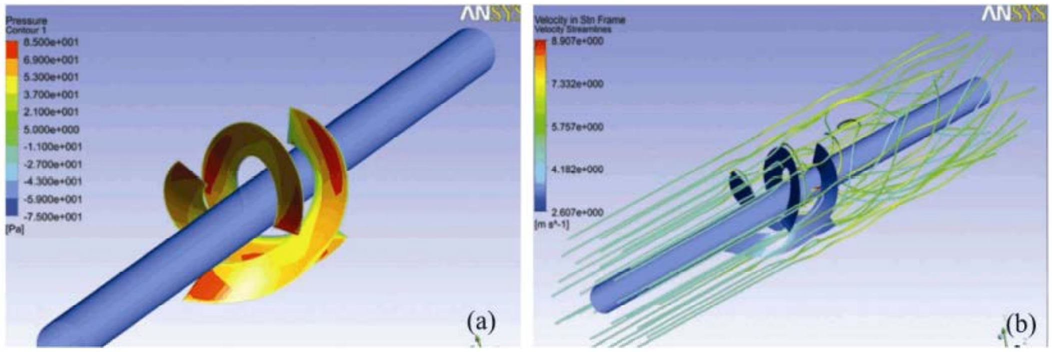

Fig. 4: (a) Pressure distribution on the blade surface, (b) Velocity streamlines at the inlet and outlet blade surface

Fig. 5: Final assembly and testing arrangement

Table 3: Results obtained for optimum distance

Air Speed m/s	Distance ft.	RPM	ω rad/s	Force N	Torque Nm	Power Experimental Watts	C_p
8.5	1.0	128	13.41	35	2.8	37.54	0.16
8.5	1.5	135	14.14	37.8	3.02	42.76	0.19
8.5	2.0	143	14.98	39.5	3.16	47.33	0.21
8.5	2.5	150	15.71	41.4	3.31	52.04	0.23
8.5	3.0	161	16.87	43.7	3.49	58.96	0.26
8.5	3.5	175	18.33	46.3	3.70	67.90	0.30
8.5	4.0	184	19.28	48	3.84	74.02	0.33
8.5	4.5	180	18.86	46.9	3.75	70.75	0.31
8.5	5.0	172	18.02	45.8	3.66	66.02	0.29
8.5	5.5	165	17.29	44.2	3.53	61.12	0.27
8.5	6.0	157	16.45	42.7	3.41	56.18	0.25

can be nearly uniform and back pressure of wind striking the rear wall could not be able to affect the RPM and at the stated distance maximum power coefficient (C_p) was achieved. Results are summarized in Table 3. Experimental power (Watts) was calculated by torques obtained in the Table using equation 3.

$$\text{Power Experimental (W)} = \text{Torque (N.m)} \times \omega \text{ (rad/s)} = \text{Torque (N.m)} \times \text{RPM} \times 2\pi/60 \qquad (3)$$

Fig. 6: Wind tunnel used for experiments

The wind tunnel used for experiments is shown in Fig. 6.

CONCLUSIONS

CFD analysis provided optimized helix angles for the spirals of the horizontal axis wind turbine with given inner and outer rotor diameters. The maximum performance coefficient (C_p) of 0.488 is obtained at a wind speed of 5 m/s and a rotational speed of 100rpm. As per optimized spiral rotor dimensions, a prototype were manufactured and experiments were performed. A start up speed of 0.85 m/s, maximum power of 74 watts at air velocity of 8.5 m/s was determined.

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REFERENCES

1. Gupta, K., A. Rehman and R. Sarviya, 2010. Evaluation of soya bio-diesel as a gas turbine fuel. Iranica Journal of Energy and Environment, 1(3): 205-210.
2. Nazari, M., H. Ghassemi, M. Ghiasi and M. Sayehbani, 2013. Design of the Point Absorber Wave Energy Converter for Assaluyeh Port.
3. <http://www.pakistantoday.com.pk/2011/04/power-shortfall-set-to-cross-4000mw/>
4. Parker, D.B. *Wind turbine blade assembly and apparatus*, 2009, Google Patents.
5. http://www.ptc.com/products/creo-elements-pro/.
6. <http://www.ansys.com/products/turbogrid.asp>.
7. <http://www.ansys.com>.
8. http://www.pointwise.com/<http://www.pointwise.com/>
9. Kim, B., J. Kim, K. Kikuyama, V. Rooij and Y. Lee. 3-D numerical predictions of horizontal axis wind turbine power characteristics of the scales delft university T40/500 model. in The fifth JSME-KSME fluids engineering conference, Japan. 2002.
10. Hartwanger, D. and A. Horvat, 3D Modeling of a wind turbine using CFD. in NAFEMS Conference. 2008.
11. Amano, R. and R. Malloy, 2009. CFD analysis on aerodynamic design optimization of wind turbine rotor blades. World Academy of Science, Engineering and Technology, 60: 71-75.

Persian Abstract

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چکیده

این مقاله نتایج حاصل از طراحی، تجزیه و تحلیل، ساخت و تست یک توربین بادی با محور افقی مارپیچی را ارائه می‌نماید. در مرحله اول، مدل‌سازی و آنالیز CFD انجام شده است. زاویه پره‌ها برای روتور مارپیچ با قطر خارجی و داخلی به ترتیب ۰.۸۵ و ۰.۴۵ متر بهینه‌سازی شده است. در مرحله دوم، برای بهینه‌سازی ابعاد روتور مارپیچ، یک نمونه اولیه ساخته شد. به منظور محاسبه گشتاور و قدرت، آزمایشاتی انجام شد؛ نتایج به دست آمده مورد بحث و بررسی قرارگرفت.